2003-03

Implementing a fast-pick area at Defense Distribution Center San Joaquin (DDJC)

Rush, Marvin P.; Burks, Eric H.

Monterey, California. Naval Postgraduate School

http://hdl.handle.net/10945/1139

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

IMPLEMENTING A FAST-PICK AREA AT DEFENSE DISTRIBUTION CENTER SAN JOAQUIN (DDJC)

by

Eric H. Burks
Marvin P. Rush

March 2003

Thesis Advisor: Kevin Gue
Second Reader: Kevin Maher

Approved for public release; distribution is unlimited.

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE March 2003	3. REPORT TYPE AND DATES COVERED Master's Thesis

4. TITLE AND SUBTITLE Implementing a Fast-Pick Area at Defense Distribution Center San Joaquin (DDJC)	5. FUNDING NUMBERS
6. AUTHORS Burks, Eric H., Rush, Marvin P.	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey CA 93943-5000	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.	12b. DISTRIBUTION CODE

13. ABSTRACT(*maximum 200 words*)

In a warehouse, a fast-pick-area is a region containing many items that can be retrieved quickly and inexpensively to fulfill customer orders. The Defense Distribution Center San Joaquin (DDJC) implements a similar strategy on a wider scale by designating one of many warehouses as a "fast-pick-area". We develop a plan to optimally slot the fast-pick area at DDJC using a computer model that captures the tradeoffs of storage space versus cost of replenishment from bulk storage. Our results suggest that defense distribution centers should consider implementing a fast pick area as a means of reducing operating costs.

14. SUBJECT TERMS Defense Distribution Depot, Defense Logistics Agency, Warehousing, Fast-Pick, DDJC, DLA	15. NUMBER OF PAGES 64
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)

Prescribed by ANSI Std. 239-18 298-102

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited

IMPLEMENTING A FAST-PICK AREA AT DEFENSE DISTRIBUTION CENTER SAN JOAQUIN (DDJC)

Eric H. Burks
Lieutenant Commander, United States Navy
B.A., Virginia Military Institute, 1991

Marvin P. Rush
Lieutenant Commander, United States Navy
B.S., Jacksonville University, 1992

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT
from the
NAVAL POSTGRADUATE SCHOOL
March 2003

Author:

Eric H. Burks

Marvin P. Rush

Approved by:

Kevin Gue
Thesis Advisor

Kevin Maher
Second Reader

Douglas A. Brook, PhD
Dean, Graduate School of Business and Public Policy

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

In a warehouse, a fast-pick-area is a region containing many items that can be retrieved quickly and inexpensively to fulfill customer orders. The Defense Distribution Center San Joaquin (DDJC) implements a similar strategy on a wider scale by designating one of many warehouses as a “fast-pick-area”. We develop a plan to optimally slot the fast-pick area at DDJC using a computer model that captures the tradeoffs of storage space versus cost of replenishment from bulk storage. Our results suggest that defense distribution centers should consider implementing a fast-pick area as a means of reducing operating costs.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGMENTS

The authors would like to thank the following people for their assistance in the successful completion of this thesis:

Our advisors, Dr. Kevin R. Gue and CDR Kevin Maher for providing much needed advice, support and expertise. The quality of this work is due, in large part, to their guidance.

To Professor John J. Bartholdi III, for providing the fast-pick model and his valuable expertise and support.

To all of the supervisors and employees at DDJC who gave freely of their time and selflessly supported all of our requirements. We regret that there are too many to mention individually.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

Defense Distribution Center San Joaquin (DDJC) is the Defense Logistics Agency's (DLA's) Western Strategic Distribution Platform (SDP), a large facility that serves as the primary source for material shipped to customers west of the Mississippi River, in Asia, the Pacific and Australia. DLA is responsible for a total of 22 Distribution Centers located throughout the United States, Europe, Japan, and Hawaii. [Ref. 1]

DDJC's mission is to receive, store, and ship government-owned supplies and equipment, primarily to military customers within its area of responsibility. DDJC stores a wide range of supplies and equipment that are used by the military services, including clothing and textiles, food, medical supplies, construction materials, electrical components, sonobuoys, tires for both aircraft and vehicles, and a wide array of secondary repair parts. [Ref. 2]

Many factors have influenced Distribution Centers within the DLA over the past ten years, including Defense Management Report Decision (DMRD) 902, base realignments and closures and commercial activities' reviews conducted by the Office of Management and Budget's Circular A-76. This means that all of DLA's distribution centers are being studied to determine which is more cost-effective, to maintain distribution functions as government operated, or to turn operations over to private contractors who have bid against a statement of work to provide distribution services. Eventually, all of DLA's individual distribution centers will be involved in this study. Currently, six studies have been completed with two centers remaining government operations and four centers converting to contractor operated facilities. [Ref. 1]

Even though DDJC is not currently being considered under the A-76 study, its management is concerned with consistently providing responsive, best value distribution services tailored to meet their customers' needs. [Ref. 3] DDJC's overriding purpose is to optimize productivity and operational effectiveness. The goal of man-

agement is to reduce the cost of doing business and to eliminate "non-value-added" processes and functions.

DDJC is made up of distribution facilities at three separate locations — Tracy, Lathrop, and Stockton's Rough and Ready Island, all in California. The depot is situated at a transportation crossroads and can easily accommodate a monthly average of 49,800 receipts and 311,000 shipments. DDJC stores 959,000 items valued at $5.4 billion in 54 warehouses on 1,632 acres.

Recently, DDJC reconfigured its operations. The reconfiguration shifted the majority of its workload from Lathrop to Tracy. Tracy now focuses on the receipt, storage, and distribution of fast-moving, high-demand items. This initiative was the result of a business-case analysis that revealed the shift would boost DDJC's productivity. Specifically, DDJC would be able to reduce its "pick to ship time" by 30%. As a result, more than 90% of DDJC's daily requisitions are processed at Tracy. Tracy consists of 25 warehouses and outside bulk storage areas Figure 1 containing more than 700,000 line items.

There is one central warehouse (Warehouse 16) that handles all receipt processing, packing, and shipping. The leadership at DDJC has established a goal that 90% of all Material Release Orders (MRO's) be picked from Warehouse 16. [Ref. 4]

A. WAREHOUSE OPERATIONS

Generally speaking, warehouses can be used to consolidate product, manage seasonal items, reduce shipping/response time, and allow for economies of scale and value-added processing. "Despite all of the initiatives in e-commerce, supply chain integration, efficient consumer response, quick response, and just-in-time delivery, the supply chain connecting manufacturing with end consumers will never be so well coordinated that warehousing will be completely eliminated." [Ref. 5]

Consolidating product allows for a reduction in transportation costs and provides for increased customer satisfaction. There is a fixed cost any time material is

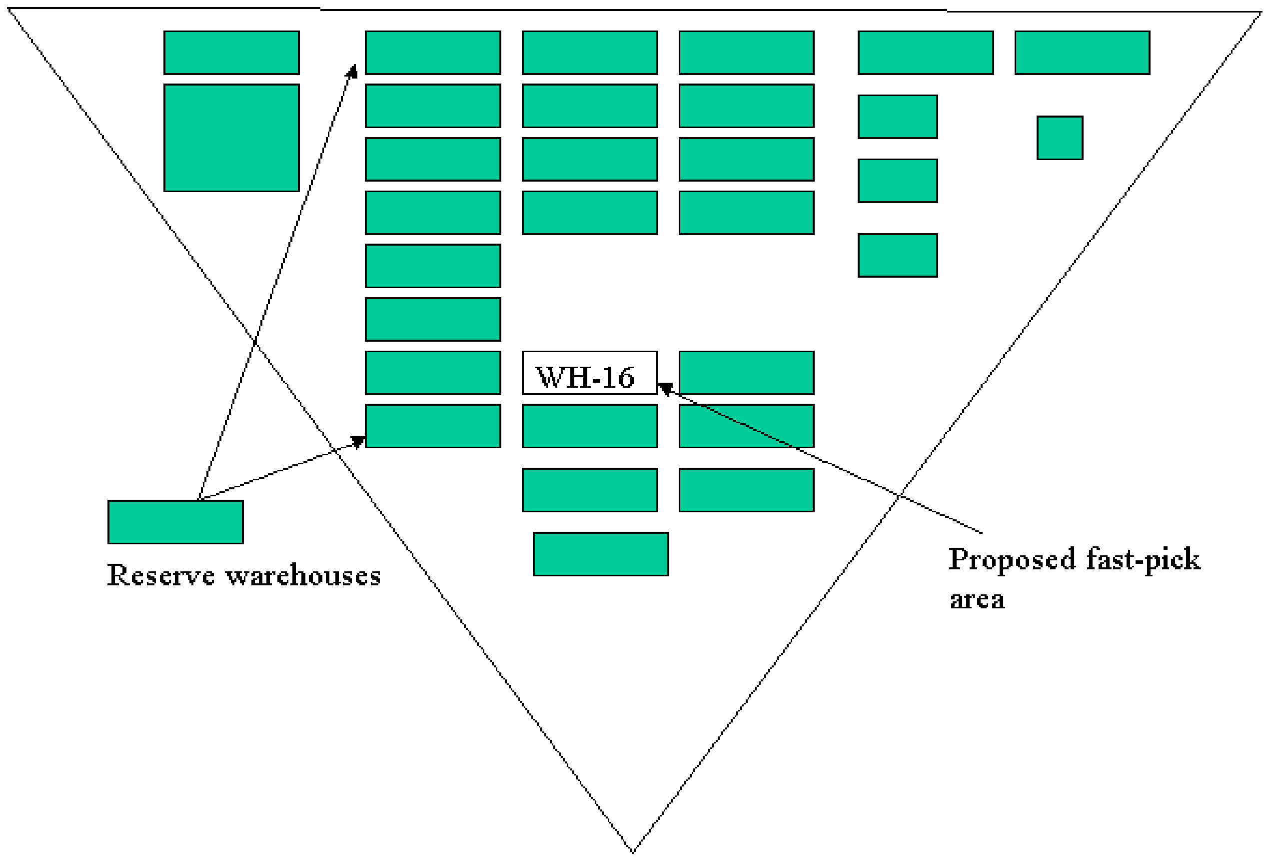

Figure 1. The Tracy Site at DDJC

transported. Consequently, distributors can consolidate shipments from vendors into large shipments for downstream customers. [Ref. 6] DDJC consolidates material from throughout the U.S. into one convenient location for follow-on shipment to end-users.

Managing seasonal products is a challenge faced by many retail stores. Many of these challenges are so big that they could not be overcome without having product stockpiled. Christmas sales surges are an excellent example. DDJC does not face seasonal challenges in this sense, but it does if one considers the transition from peacetime to war to be a "seasonal transition".

Reducing response time is a definite benefit for having a warehouse. By locating material near major highways, DDJC is in a better position to respond quickly to customer demand. Allowing for economies of scale and value-added processing are also benefits of investing in a warehouse. Value-added processing is exemplified by Dell Computer adding generic parts to their personal computers during the shipping process. Economies of scale can be realized in both manufacturing and purchasing. Often, the price breaks and large set up costs offset the expense of storing materials and product. This particular benefit is not applicable at DDJC.

Warehousing is expensive. For example, warehouses typically make up between two and five per cent of the cost of sales of a corporation. With corporations focusing on such things as returns on investment, minimizing the cost of warehouse operations has become an important issue. This is especially true within the Department of Defense. The DoD is not necessarily concerned with return on investment, but it is interested in doing business as efficiently as possible.

Though warehousing is increasing in importance in logistics and supply chain management, it is still integrated with and to a large degree dependent on other logistics activities. [Ref. 5] Despite the name or role, warehouse operations have a fundamental set of activities in common, including receiving, prepackaging, putaway, storage, order picking, packaging, pricing, sortation, accumulation, and shipping.

- Receiving is the collection of activities involved in the orderly receipt of all materials coming into the warehouse. It also includes providing the assurance that the quantity and quality of such materials are as ordered along with disbursing materials to storage or to other organizational functions requiring them.

- Prepackaging is performed in a warehouse when products are received in bulk from a supplier and subsequently packaged singly, in merchandisable quantities, or in combinations with other parts to form kits or assortments. An entire receipt of merchandise may be processed at once, or a portion may be held in bulk form to be processed later. This may be done when packaging greatly increases the storage-cube requirements or when a part is common to several kits or assortments.

- Putaway is the act of placing merchandise in storage. It includes material handling, location verification, and product placement.
- Storage is the physical containment of merchandise while it is awaiting a demand. The storage method depends on the size and quantity of the items in inventory and the handling characteristics of the product or its container.
- Order Picking is the process of removing items from storage to meet a specific demand. It is the basic service a warehouse provides for customers and is the function around which most warehouse designs are based.
- Packaging or pricing may be done as an optional step after the picking process.
- Sortation of batch picks into individual orders and accumulation of distributed picks into orders must be done when an order has more than one item and the accumulation is not done as the picks are made.
- Shipping may include the following tasks: checking orders for completeness, packaging merchandise in appropriate shipping containers, preparing shipping documents, weighing shipments to determine shipping charges, and accumulating orders by outbound carrier and loading trucks.

B. FAST-PICK AREAS

Warehouses can become more efficient by separating their storage and picking activities. Specifically, savings in operating costs will be realized by reducing the amount of labor required to retrieve and restock items in the warehouse. One way to separate these activities is by designating a fast-pick area. A fast-pick area is a separate space from which the large majority of the picks are made. It is essentially a sub-region of a warehouse. Creating a fast-pick area has many benefits, including reduced picking costs and increased responsiveness to customer demand. However, there is a science to configuring a fast-pick area.

When considering the development of a fast pick area it is helpful to view warehouse operations as product flowing through the warehouse. Material typically arrives at a site packaged on a large scale and as it flows through the warehouse it is broken down from large pieces of product and redistributed in smaller quantities. Warehouse operations can also be categorized into the following functions:

1. Receiving bulk shipments
2. Staging material for quick retrieval
3. Retrieving material in response to customer demand and
4. Shipping material.

Of these four functions, retrieving/sorting material in response to customer demand accounts for 55% of overall warehousing costs. [Ref. 6]

The idea of a fast pick area is basically a warehouse within a warehouse. The majority of warehousing costs comes from workers picking material. [Ref. 5]

Activity	% of Warehouse Operating Costs
Receiving	15%
Storage	15%
Picking	55%
Shipping	15%

Order picking can be further broken down as follows:

Activity	% Order-picking time
Traveling	55%
Searching	15%
Extracting	10%
Paperwork and other activities	20%

There are significant savings possible by strategically locating material in a fast pick area with the goal of minimizing overall operating costs. By conveniently locating fast moving items in a concentrated area, labor costs can be significantly reduced. [Ref. 6] Labor costs go down because workers do not have to travel as far to make picks; however, there is a tradeoff: items in a forward area must be restocked from bulk locations elsewhere in the warehouse, and this is an additional cost.

Configuring a fast-pick area is not as simple as locating the fastest moving items in a particular area. We must also consider how large the area should be and the optimal quantity of a particular item to store in the fast pick area. If the area is too large, then more travel is required per pick which results in less savings per pick.

If the area is too small, then fewer items can be stored there, and they have to be restocked more often, which increases costs. If too much of an item is stored, then less space for other items is available. If too few of an item is stored, then it has to be restocked too often.

C. A FAST-PICK WAREHOUSE AT DDJC

DDJC Management is interested in implementing these ideas at their Tracy site. They have already established as a goal that 90% of their picks come from one centrally located warehouse as a means of becoming more efficient. They have already moved Stock Keeping Units (SKU's) into and out of their Warehouse 16 towards this goal, but they have not benefited from the science of a fast-pick area.

Warehouse 16 was chosen based on its central location and the fact that the receiving, packing and shipping sections are already located there. DDJC views this central location as a logical choice for consolidating their labor. We have described a fast-pick area as a warehouse within a warehouse. DDJC proposes to use the entire warehouse as a fast-pick area with the surrounding warehouses serving as the reserve storage areas. This concept differs from the idea of a warehouse within a warehouse, but is basically the same, only on a larger scale.

To assist DDJC in converting Warehouse 16 into a fast-pick area and benefit from the ideas we have described, the following relevant questions must be answered:

- Which SKU's should be stored within Warehouse 16?
- In what quantities should they be stored within Warehouse 16?
- How should DDJC transition from their current operations to Warehouse 16 as a fast-pick area?

THIS PAGE INTENTIONALLY LEFT BLANK

II. DESIGNING A FAST-PICK AREA

Following is a synopsis from Bartholdi and Hackman (2002), describing the theory and mathematics of a fast-pick model. [Ref. 7]

A. WHAT IS A FAST-PICK AREA?

A fast-pick area functions as a "warehouse within a warehouse" [Ref. 5] , in which the most popular sku's are kept in relatively small quantities, so that the majority of the picking occurs within a relatively small area. This enables pickers to do more picking with less walking and allows them to be more easily supervised. The trade-off is that the fast-pick area must be replenished from a bulk storage, or reserve location. The internal replenishments are a sort of "fixed cost" associated with maintaining the fast-pick area.

The basic issues in the design of a fast-pick model are:

- Which sku's should be stored in the fast-pick area, and
- What quantity of each sku should be stored in the fast-pick area?

To answer these questions, we must determine the optimal number of each sku to store in the fast-pick area. If an sku is stored in an insufficient quantity then the cost of restocking can outweigh any savings gained from reduced picking costs. Conversely, if an item is stored in excess quantity then the limited space available is wasted on that sku.

Bartholdi and Hackman answer these questions by using a "fluid model" which treats each sku as an incompressible, continuously divisible fluid. That is, they ignore the actual dimensions of sku's which come in pallets, cases or individual units.

The fluid model is easily realized, and its results are the benchmarks or goals because they represent the ideal.

B. ESTIMATING RESTOCKS

The first step toward implementing the fast-pick model is to determine the cost of restocking since restocking is how the fast-pick area will be maintained. The cost of restocking depends on the specifics of each warehouse; costs may be influenced by

- The number of restocks required by each sku,
- The quantity of each sku to be replenished, and
- The time restocks occur (during normal working hours or after hours).

To keep the model simple, the cost of restocking is based mainly on the required number of restocks. The number of restocks is based on the storage unit: If the sku is stored as a pallet then each pallet requires separate handling. If the sku is stored in smaller units, cases or eaches, then the number of restocks can be estimated by the fluid model. Consider sku i of which volume v_i cubic-feet is stored in the fast-pick area. How often must i be restocked? That depends on its rate of flow f_i through the warehouse. Flow is measured in cubic feet per year and may be determined from warehouse data as follows:

$$f_i = \left(\frac{\#items/year}{\#items/case}\right)\left(\frac{cubicfeet}{case}\right)$$

If sku i flows through the warehouse at rate f_i cubic feet per year then sku i will require approximately f_i/v_i restocks per year.

C. STORING OPTIMAL AMOUNTS

Once the decision has been made as to which sku's will be in the fast-pick area, the question is how much space to allocate to each sku? The (variable) cost of storing v_i cubic feet of sku i is the cost of restocking it: The more stored, the fewer restocks required, but this leaves less space for other sku's. If the cost of each restock is c_r, then the cost per year of storing v_i cubic feet of sku i may be estimated as $\frac{c_r f_i}{v_i}$.

Some assumptions are:

- Restocks only occur after v_i is exhausted.
- The "variable" cost of each restock is independent of the quantity restocked. This is more applicable to small sku's which will be replenished by cases. This will not hold true for sku i restocked by pallet; one restock is required for each pallet consumed, so restocks are dependent on the quantity stored.

D. ALLOCATING SPACE IN THE FAST-PICK AREA

The goal is to minimize restock costs which will require the right amount of each sku to be stored in the available space. The total volume available for sku's will be V measured in cubic feet. We define the following notation:

- c_i The net benefit of stocking sku i in the fast-pick area in amount v.
- c_r Cost of a single restock.
- f_i Flow of sku i through warehouse in cubic feet per year.
- p_i Annual number of picks for sku i.
- rop_i Reorder point for sku i.
- s Savings realized when pick is made from fast-pick area.
- V The total available cube in the fast pick area.
- v_i Amount of sku i stored in fast-pick area.

Our goal is to

$$min] \sum_{i=1}^{n} c_r f_i / v_i$$

Subject to

$$\begin{aligned} \sum_{i=1}^{n} v_i &\leq V \\ v_i &\geq 0. \end{aligned}$$

To solve this non-linear programming problem a two phased approach is used. Bartholdi and Hackman define the expression $p_i/\sqrt{f_i}$ to be the *viscosity* of sku i,

since it represents the labor required to move a given flow through the warehouse. All potential sku's to be placed in the fast-pick area are ranked by viscosity, highest to lowest. The first sku (highest viscosity) is put in V and a cost is determined, then the first two sku's are put in space V and the cost is determined, then the first three, and so on. This approach is continued until costs are minimized and adding the next sku increases the cost from the previous sku's that were placed in V. This is the point where costs are minimized.

Bartholdi and Hackman develop the following:

Theorem 1 *To minimize total restocks over all sku's j=1,..n,each sku i should be stored in the amount*

$$v_i^* = \left(\frac{\sqrt{f_i}}{\sum_{j=1}^{n} \sqrt{f_j}} \right) V. \tag{II.1}$$

So, by having a higher flow or viscosity means more of the sku will be picked. So it would be more cost effective to give it more of V to reduce the total number of restocks and get more picks from the fast-pick area at the lower cost per pick.

E. MINIMUM AND MAXIMUM ALLOCATION OF SPACE

The fluid model was developed by Bartholdi and Hackman to optimally slot sku's within a warehouse to reduce the total picking costs associated with operating a warehouse. Because it ignores actual product demensions, the model will sometimes suggest storing impractically small quantities of large, slow-moving sku's. This can be a problem when there are minimum quantities of sku's that are required to be carried. Less space cannot be allocated to an sku than a single unit of that sku will occupy. The fluid model can account for this anomaly. To ensure that no sku receives less than its specified minimum amount of space, space is allocated for sku's according to Equation II.1; then the following steps are repeated until either all sku's have received enough space or there is no more space available.

- If there are any sku's that received less than their minimum required space, identify them and have all other sku's return their space to be reallocated.

- Provide all the deficient sku's with their minimum space requirements. Remove the sku's and their space from the problem.
- Reallocate the remaining space among the remaining sku's.

Additionally, maximum space allocations need to be enforced. It would not be practical to allocate more space to an sku than is necessary for its maximum on-hand inventory. The above procedure can be used to enforce the upper bounds on space allocations for maximums as well as minimums.

F. HOW TO DETERMINE WHICH SKU'S GO IN THE FAST-PICK AREA

In a warehouse there are some sku's that are slow moving compared to other sku's. It is not reasonable to allocate the limited storage space in a fast-pick area to these slow moving sku's. It is better to give more space to the faster moving sku's and reduce the number of restocks. This will reduce the restock cost but it will occasionally require that picks of the slow moving sku's be made from deep within the warehouse or outlying warehouses, which is more expensive than picking from the fast-pick area.

In order to concentrate on the fast-pick area, it is assumed that the rest of the warehouse or outlying warehouses (aka "the reserve") is large enough so space is not an issue.

Let s be the savings gained when a pick is made from the fast-pick area instead of the reserve. Let p_i be the number of picks forecast for sku i during the year. The net benefit of storing sku i in the forward area in amount v_i is given by

$$c_i(v_i) = \begin{cases} 0 & if \text{ v= } 0 \\ sp_i - c_r f_i / v_i & if \text{ v> } 0 \end{cases}$$

The net benefit is zero if sku i is not stored in the forward-pick area; otherwise the net benefit is the total yearly savings minus the cost of restocks.

Theorem 2 *The sku's that have the strongest claim to the fast-pick area are the ones that have the greatest viscosity.*

The problem of deciding which sku's belong in the fast-pick area can now be solved. It can be determined which sku's go in the fast-pick area and which ones do not. The following steps are used to determine the sku's to be stored in the fast-pick area and in what amounts.

- Sort all sku's from most viscous to least.
- Successively evaluate the total net cost of putting no sku's in the fast-pick area; putting only the first sku in; only the first two sku's in; and so on. Choose the combination that minimizes net cost.

To determine the net cost: Charge each sku for each of its p_i picks and f_i/v_i restocks.

Theorem 3 *Choosing sku's based on viscosity will result in a fast-pick area of total net-benefit that is no farther from optimum than the net-benefit of a single sku.*

This process solves the problem of stocking the fast-pick area to realize the greatest possible net benefit.

G. REORDER POINTS

Bartholdi and Hackman assume that f_i/v_i is a sufficient estimate of the restocks, which assumes that restocks are only conducted after a stockout. Restocking prior to a stock out is preferred to avoid delays for issues. This can be accounted for by requiring sku i to be restocked when its inventory level reaches a preset reorder point rop_i. Sku i will be restocked $f_i/(v_i - rop_i)$ times. This causes the previous results for the ideal amount of storage, pick density and viscosity to be a little more complicated. The optimal amount of sku i to store given by Expression II.1 now becomes:

$$v_i^* = rop_i + \left(\frac{\sqrt{f_i}}{\sum_j \sqrt{f_j}}\right)\left(V - \sum_j rop_j\right)$$

Sku i will be stored in an amount at least equal to rop_i and the remaining space is divided up according to the square root of the flow. [Ref. 7]

THIS PAGE INTENTIONALLY LEFT BLANK

III. WAREHOUSE OPERATIONS AT DDJC

A. WAREHOUSE STOWAGE AND PICKING TYPES

Warehouse 16 is the central hub of DDJC. It contains 354,984 cubic feet of storage space, in horizontal carousels, bin storage and nestainers. There is also a mezzanine with bin shelving and carousels.

Picking systems are the functions around which most warehouse designs are based. The major types of broken case picking systems are "picker-to-stock" (PTS) systems, "stock-to-picker" (STP) systems, and automated item picking. DDJC utilizes both the PTS systems and STP systems. There is no automated stock picking at DDJC.

In picker-to-stock systems, the order picker walks or rides to the picking location. The two subsystems that must be selected are the storage system that houses the stock and the item retrieval system. The most popular alternatives for picker-to-stock storage systems are bin shelving, modular storage drawers, and gravity flow racks. DDJC's warehouses have bin-shelving systems.

1. Bin Shelving

Bin (or metal) shelving systems are the oldest and still the most popular equipment alternative for small parts order picking. Bin shelving systems are inexpensive ($100 to $150 per unit), easily reconfigured, and require very little maintenance. With bin shelving systems, the money saved initially may be lost in the long run due to increased space and labor requirements. Space is frequently underutilized in bin shelving systems because the full dimensions of a shelving unit are rarely usable. Also, because people may be walking and extracting the items, the height of bin shelving units may be limited by the reaching height of a human being. As a result, the available building cube may also be underutilized. The consequences of low space utilization are twofold. First, low space utilization means that a large amount of floor space is required to store the products. The more expensive it is to own and operate

the space, the more expensive low space utilization becomes. Second, the greater the floor space, the greater the area that must be traveled by the order pickers, and thus the greater the labor requirement and cost. Two additional drawbacks of bin shelving are supervisory problems and item security problems. Supervisory problems arise because it is difficult to supervise people through a maze of bin shelving units. Security and item protection problems arise because bin shelving is open; that is, all the items are exposed to and accessible from the picking aisles by any operator/visitor. [Ref. 5]

Picker-to-stock (PTS) retrieval methods include cart picking, tote picking, man-aboard systems, and robotic item picking. DDJC incorporates both cart picking and tote picking into their warehouse operation.

2. Cart Picking

A variety of picking carts is available to facilitate accumulating, sorting, and/or packing orders as an order picker makes a picking tour. Conventional carts provide dividers for order sortation, a place to hold paperwork and marking instruments, and a stepladder for picking at levels slightly above reaching height. Batch picking carts are designed to enable an order picker to pick multiple orders on a picking tour, thus dramatically improving productivity as opposed to strict single order picking for small orders. More sophisticated carts automatically transport an order picker to a pick location, use light displays to direct the order picker to sort the contents of a pick into the correct order position, and permit mobile online communications via RF links and/or wireless local area network links. [Ref. 5] Unfortunately, none of these sophisticated cart innovations are being used at DDJC.

3. Tote Picking

In tote picking systems, conveyors are used to transport tote pans (or shipping cartons) through successive picking zones to enable order completion. The tote pans are used to establish order integrity for merchandise accumulation, containment, and/or shipping. Order pickers may walk one or more totes through a single picking

zone, partially completing several orders at a time; or an order picker may walk one or more totes through all picking zones, thus completing one or more orders on each pass through the picking zones. The improvement over cart picking must be sufficient to justify the additional investment in conveying and sorting systems. [Ref. 5] While DDJC has chosen to use a combination of cart and tote picking, the majority of their pickers use a cart picking system.

The two major types of stock-to-picker systems are carousels and miniload automated storage/retrieval systems. The major advantage of stock-to-picker systems over picker-to-stock systems is the elimination of the travel time for the order picker. When wage rates are high, the labor savings can be sufficient to justify the investment in the mechanical and control systems required in stock-to-picker systems. Another advantage of stock-to-picker systems is supervision. In stock-to-picker systems, the picking takes place at the end of an aisle. Hence, all of the operators should be visible to a supervisor in one quick glance down a picking line. [Ref. 5] DDJC has a portion of Warehouse 16 outfitted with a horizontal carousel system.

4. Carousels

A horizontal carousel is a linked series of rotating bins of adjustable shelves driven on top or on the bottom by a drive motor unit. As the bins rotate by order pickers who occupy fixed positions in front of the carousel(s) extract items from the carousel. Order pickers may also be responsible for controlling the rotation of the carousel. Manual control is achieved via a keypad that tells the carousel which bin location to rotate forward and a foot pedal that releases the carousel to rotate. Carousels are normally computer-controlled, in which case the sequence of pick locations is stored in a computer and brought forward automatically. One drawback of horizontal carousels is that the throughput is limited by the rotation speed of the motor drive. Another drawback is the initial investment of $40,000 to $70,000 per carousel unit. Consequently, items with a high cube movement should not be housed in carousels because the carousel may not be able to rotate fast enough to permit

sufficient access to those items and because those items would occupy a large and expensive envelope of space in the carousel. [Ref. 5]

The nestainers (nesting type pallet stacking frames) in Warehouse 16 are self-contained steel units made up of decks and posts. Stacking frames are portable and allow the user to stack material several loads high. The nestainers in Warehouse 16 are stacked three high. The major advantage of this type of storage is full accessibility to all unit loads. The major disadvantage is the amount of space that is required for aisles. (typically 50% to 60% of the available floor space) [Ref. 5]

Mezzanines are used as additional space for bin shelving and carousels. The advantage of using a mezzanine is that almost twice as much material can be stored in the original floor space. [Ref. 5]

Located within Warehouse 16 are the receiving, packing and shipping sections Figure 2. All of these sections are connected via a conveyor system. Warehouse 16 is also connected to warehouses 15, and 17 via a conveyor system. The only items that are allowed to be stored in Warehouse 16 are "binnable" items. Binnable items have to be five pounds or less per unit and able to fit within the available storage locations.

These locations are identified by Type Storage Codes (TSC's). Each TSC represents a unique location used for sku storage at DDJC. The various TSC's used in the carousels and bin shelving are made up of cardboard inserts that are cut to the desired dimensions. These inserts are not used in the nestainer storage area. The TSC's listed in Table I are specific to Warehouse 16. Only these "binnable" items can be transported on the conveyor system. This limitation does not apply to the conveyor between packing and shipping which is capable of moving palletized material.

DDJC operates six days a week, twenty four hours a day. They operate on a three shift schedule with varying numbers of employees to ensure that enough workers are available as needed. Table II provides a detailed work schedule of employees

TSC	Weight(lbs)	Cube(ft)	Height(in)	Width(in)	Length(in)
AA1	67	.2	4	6	19
AA2	67	.25	4	6	23
AA3	80	.3	4	9	19
AA4	80	.38	4	9	23
AA5	100	.5	10	9	19
AA6	100	.6	10	9	23
AA7	135	1.045	10	12	19
AA8	135	1.25	10	12	23
AAA	20	.06	4	4	7
AAB	20	.1	4	5	10
AAC	20	.41	9	7	10
AAD	25	.67	9	6	21
AAE	30	.8	10	6	23
AAF	40	1	9	9	21
AAG	65	1.6	10	17	17
AAH	80	2	10	17	23
AAI	200	7.46	21	38	19
AAK	125	3.2	10	34	17
AAL	160	4	10	34	23
AAM	180	4.5	20	16	28
AAN	225	5.7	19	34	17
AAO	200	9.03	21	38	23
AAP	200	8	19	34	23
AAT	400	17.3	23	45	29
AAX	400	10	30	38	19
AAY	400	11.35	30	38	23
RAW	400	34	78	24	35
A70	400	48	48	48	48

Table I. Type storage codes in place at DDJC with their dimensional data.

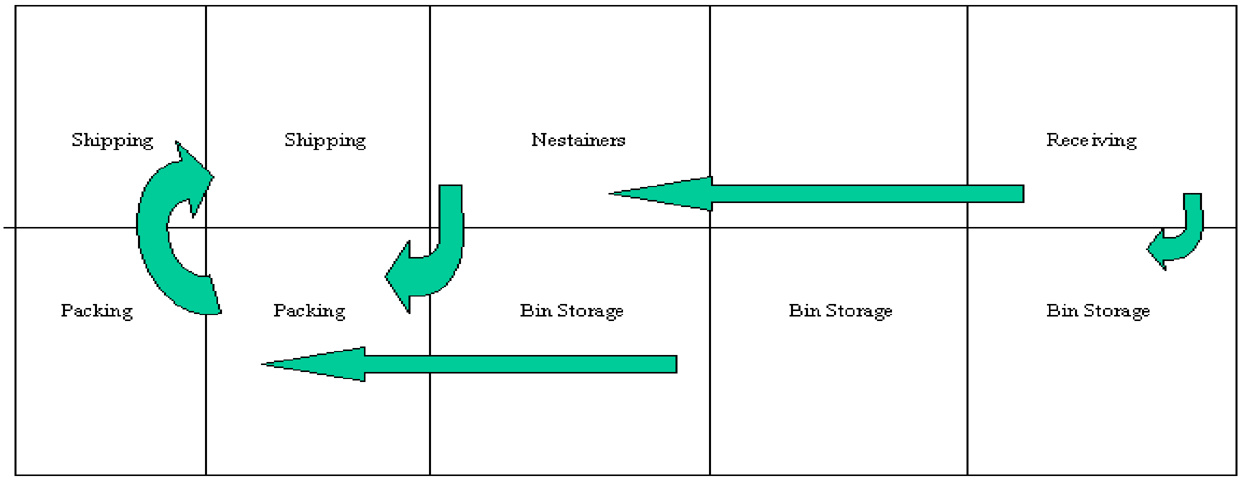

Figure 2. Warehouse 16 layout. Arrows depict sku movement from receiving to shipping.

assigned to Warehouse 16. The only times Warehouse 16 is not in operation is from 2230 on Saturday to 2200 on Sunday and federal holidays. [Ref. 8] [Ref. 9]

Shift	**Days**	**Time**	**Employees**
First	Monday-Friday	0600-1430	18
First	Tuesday-Saturday	0600-1430	28
First	Wednesday-Saturday	0600-1630	8
Second	Monday-Friday	1400-2230	17
Second	Tuesday-Saturday	1400-2230	14
Third	Sunday-Thursday	2200-0630	15
Third	Monday-Friday	2200-0630	10

Table II. Storage Branch employee work schedule, Warehouse 16.

The majority of the effort expended in Warehouse 16 is directed towards order picking. This demand is provided to the employees in the form of Material Release Or-

ders (MRO's), which are received in Warehouse 16 on the following schedule Monday through Friday:

- Cycle 1: Automatically release at midnight (0000).
- Cycle 2: Automatically release at 0200.
- Cycle 3: Scheduled to release at 1300.
- Cycle 4: Schedule to release at 1600.

After Cycle 2, accumulated requisitions in the system are closely watched by two Supply Management Specialists. Once the requisitions build up to more than 3,000 lines they will automatically drop them. If they do not reach the 3,000 cut-off they will wait until the scheduled release times. Warehouse 16 receives five or six cycle drops daily. [Ref. 10]

In addition to active picking, employees also restock the storage locations in Warehouse 16. This involves two different scenarios. They include the storage of new material (items that have not previously been carried at DDJC) and replenishment of depleted sku's as material is issued from Warehouse 16.

B. REPLENISHMENT POLICY

Restocks are "triggered" by location and not by sku. By this, we mean that when a location reaches 25% of its maximum storage, Distribution Standard System (DSS) automatically generates a replenishment order to one of the outlying warehouses where reserve material is stored. Maximum storage is based on a 120-day supply determined from demand history (Note that this is the so-called Equal Time Supply policy described in Bartholdi and Hackman (2001)). Any inventory in excess of 120 days is stored in the reserve warehouses. When restocks are "triggered" based on location instead of individual sku depletion excessive restocks occur. [Ref. 10]

Multiple locations, the cause of this excessive restocking, are a result of random storage. By this, we mean that sku's do not have dedicated storage within Warehouse

16. Instead, storage locations are randomly selected to accommodate the volume of each sku. Table III shows the number of sku's with multiple locations.

Number of Locations	**Number of Sku's**
1	136628
2	29107
3	7204
4	2286
5	927
6	357
7	202
8	124
9	64
≥ 10	164

Table III. Number of sku's with multiple locations in Warehouse 16.

When a location reaches the 25% "trigger" point DSS generates a request that is printed out in one of the reserve warehouses where the material is stowed. Workers pack the material, palletize it, and place it on the loading dock at each individual reserve warehouse awaiting pick-up by transporters and flat-bed operators for delivery to Warehouse 16. Each warehouse calls the dispatcher Monday-Saturday 0700-1530 when it has a delivery ready. All other times drivers randomly circle the base looking for material staged on loading docks ready for movement.

C. INTERNAL RESTOCKING

Material is delivered to the Warehouse 16 loading dock during all shifts. Material is placed in the staging area to accumulate throughout the day and is only processed for storage during the second shift. There is one employee dedicated to this task. Her primary function is to validate that the storage location assigned by DSS is large enough to accommodate the sku assigned for storage. There are significant problems with DSS that require human intervention in this process. Specifically, missing or inaccurate dimensional data require the employee to physically measure

each sku and input the correct cube data before DSS will assign it a correct storage location. We observed her using a ruler that was taped to her workstation for the purpose of measuring each sku; when asked how often she had to measure sku's she responded approximately 50% of the time. This prevents the use of scanner technology in the restocking process. DDJC recognizes this as a problem prevalent throughout DLA. There is a current initiative within DLA for each distribution center to validate and correctly enter the weight and cube of 1,000 sku's per month until this problem is corrected. [Ref. 11]

After these problems with DSS are overcome she places a new stow ticket (identifies location and bin for storage) on each sku. These sku's are then distributed throughout the warehouse for storage. The same procedures apply for new material (items that have not previously been carried by DDJC) with the same problems mentioned before.

DDJC conducted an internal study and determined the cost to pick from the reserve areas to be $1.69 per sku. The cost to pick from Warehouse 16 is $0.50 per pick. The cost to restock Warehouse 16 is $3.28 per restock, Figure 3. [Ref. 12]

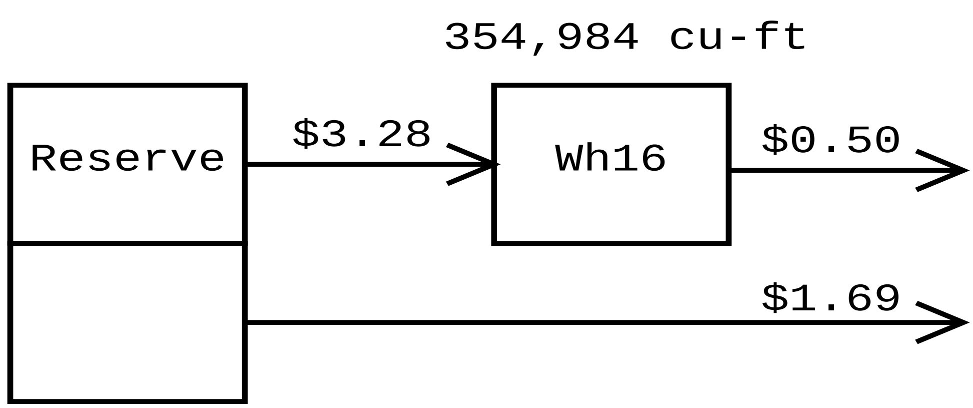

Figure 3. Cost of making picks from Warehouse 16, reserve warehouses and the cost to restock Warehouse 16

There are currently 288,000 sku's stored in Warehouse 16. During the time period used for this study there were 1,657,826 picks made from Warehouse 16 at a cost of $828,913. During the same period there were 9,000 restocks in Warehouse 16

at a cost of \$29,520. There were 2,801,903 picks made directly from reserve areas at a cost of \$4,735,216.07.

D. WAREHOUSE 16 ACTIVITY PROFILING

Warehouse profiling is the analysis of activity at a particular warehouse. It can identify major opportunities for process improvements and provide a basis for project decision making. Done properly, it can highlight warehouse design and planning opportunities that might not naturally be discovered. [Ref. 5]

An initial review of the sku's eligible for storage in Warehouse 16 uncovered some suspicious dimensional data. These anomalies disqualify these sku's from slotting in the fast-pick area. They include:

- Linear dimension anomalies:
  - Missing 46,961 sku's with one of Length (L), Width (W), or Height (H) equal to 0.
  - Too small 8,755 sku's with L, W, H all greater than 0 but one less than 0.1 inch.
  - Too large 19,315 sku's with one of the L, W or H exceeding 60 inches.
- Unit cube anomalies
  - Missing 1,442 sku's with $L \times W \times H = 0$ and Unit Cube = 0.
  - Missing but can be estimated 5,134 sku's with L, W, H > 0 but Unit Cube = 0 (can estimate as $L \times W \times H$)
  - Too large 141 sku's with unit cube exceeding 100 cubic-feet.
- Unit cube smaller than predicted:
  - 1,367 sku's with $0 <$ Unit Cube $< L \times W \times H - 0.1$ cubic-feet.
  - 26,204 sku's with Unit Cube exceeding $L \times W \times H$ by at least 5%.
- Unit cube larger than predicted:
  - 7,394 sku's with $0 < L \times W \times H <$ Unit Cube - 0.1 cubic feet.
  - 86,726 sku's with $L \times W \times H$ exceeding Unit Cube by at least 5%.

Sometimes a minority of the items in a warehouse generate a majority of the picking activity. Out of the 700,000 sku's carried by DDJC only 417,000 are eligible for storage within Warehouse 16, due to size and weight of the material, classified items, hazardous material, and so on. Textiles and clothing are also exempt from storage in warehouse 16 due to their bulkiness.

It is interesting to note that a small percentage of the sku's carried in Warehouse 16 are responsible for a surprisingly large number of the picks. Figure 4 represents the popularity or number of picks per sku from the sku's that are eligible for storage in Warehouse 16. This data indicates that 12% of the Warehouse 16 eligible sku's account for more than 60% of all picks made. This suggests that DDJC will benefit from concentrating the storage of these items in an area close to their point of conveyance.

Carrying excessive amounts of individual sku's also takes up valuable storage space. As depicted in Table IV, 20% of sku's have more than five years of stock on hand (based on current demand) and account for over 1.4 million cubic-feet of available space. Table V represents the top eight sku's with excessive inventory on hand.

Time-supply	**#-sku's**	**Fraction of sku's**	**Cubic-feet**
10+years	33,556	8%	864,077
5-10 years	23,196	6%	265,948
3-5 years	23,070	6%	240,309
1-3 years	62,880	15%	823,439
0-1 years	274,043	65%	1,548,579

Table IV. A list of the number of sku's that account for an excessive amount of the available storage space.

An analysis of the data revealed that a majority of the sku's run out on a predictable basis, evidenced by noticeable spikes at 30, 120, 180 and 210 days. These spikes are probably the result of a large number of sku's with low demand and low

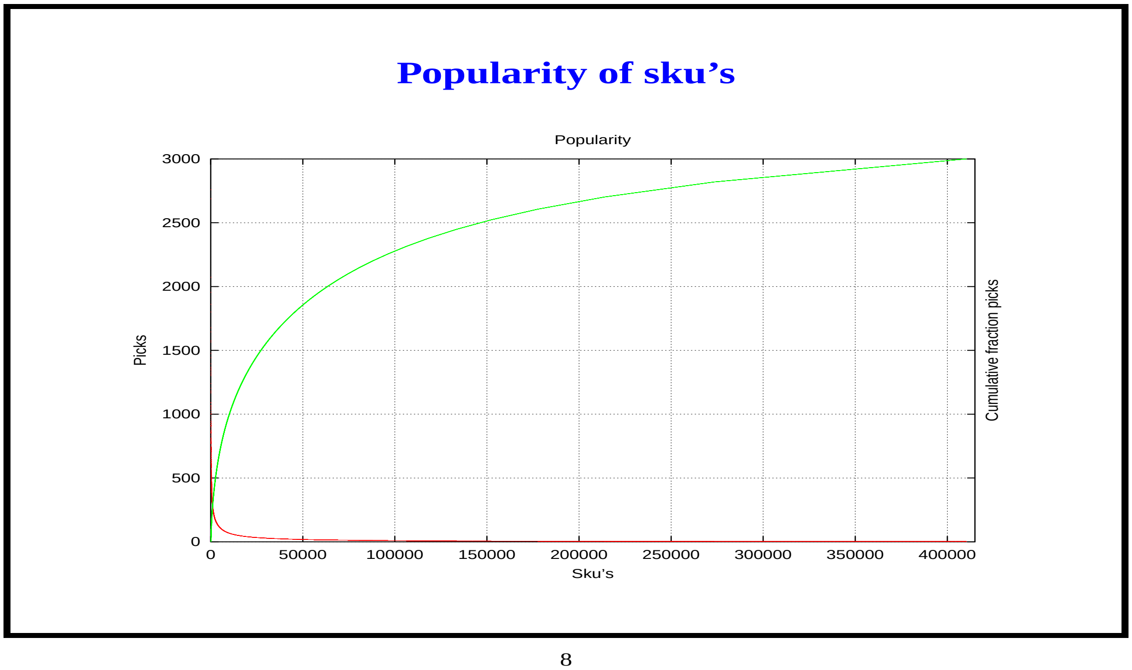

Figure 4. Graphical representation of the picks per sku. The curve with the positive slope shows the cumulative number of picks starting with the most popular sku and ending with the least popular sku. The curve with the negative slope depicts the quantity of picks associated with individual sku's. (From [Ref. 13])

quantity on hand. For example, if a sku has an on hand balance of one with an annual demand of two it would result in 180 days of supply. This is indicated by the largest spike at 180 days supply.

Sku	Nomenclature	Qty	MROs	OnHand	Yrs
5960001794446	ELECTRON T	4	2	153,890	38412.5
5960005034880	ELECTRON T	2	2	39,876	19,938.0
5960002620210	ELECTRON T	6	2	94,366	15,727.7
8415010841686	CAP,CAMOUF	3	3	45,000	15,000.0
5310005432277	NUT SPACER	2	2	24,718	12,359.0
8465014164634	SPECTACLES	2	2	21,903	10,951.5
5325002828157	EYELET,MET	2	2	19,978	9,989.0
5330001660975	O-RING	9	3	81,261	9,029.0

Table V. A list of sku's with low demand that have an excessively high on-hand inventory.

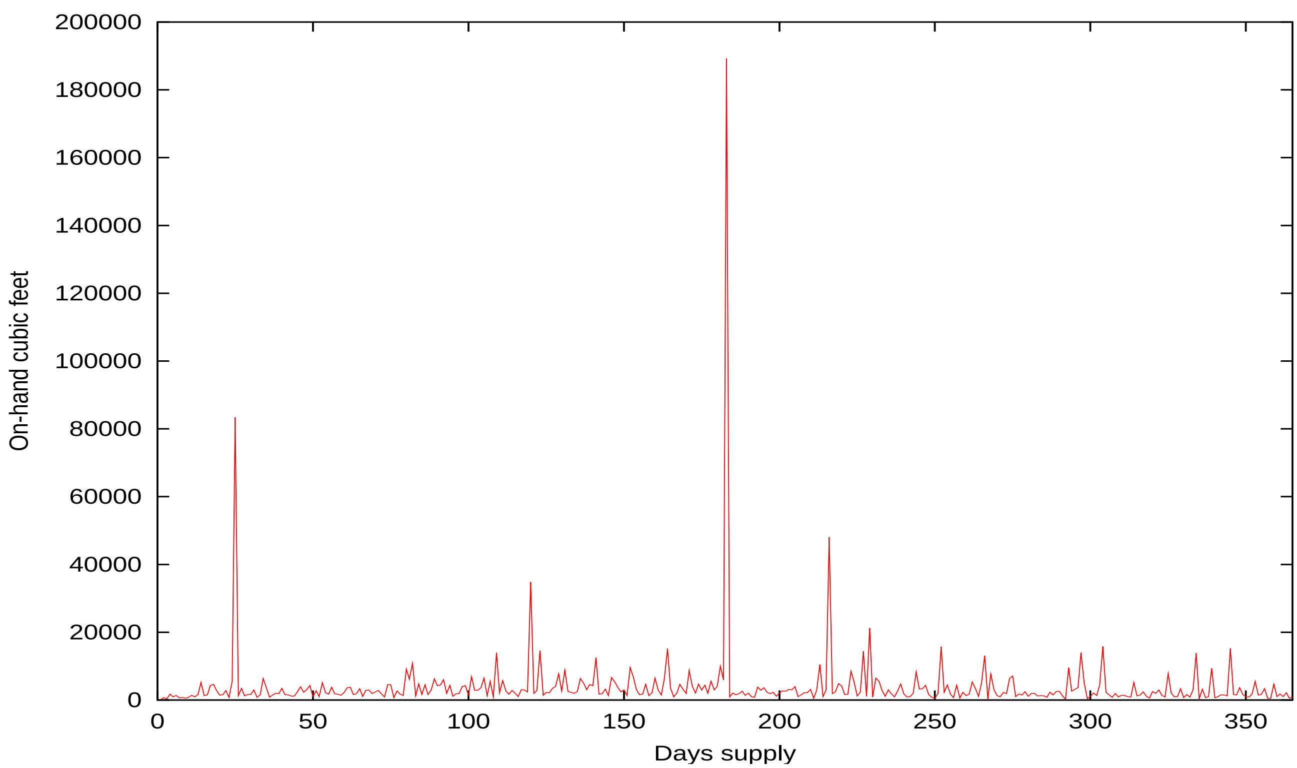

Figure 5. Graphical representation of estimated time supplies of on-hand inventory. The noticeable spikes indicate a predictable pattern of stock outages. (From: [Ref. 13])

THIS PAGE INTENTIONALLY LEFT BLANK

IV. ANALYSIS AND RESULTS

A. THE FLUID MODEL

The fluid model captures the trade-off between the conveniences of storing material in Warehouse 16 and the cost of restocking it, but ignores the geometry of individual sku's and storage containers, the weight of material, and the placement of storage containers on shelves. Nevertheless, the fluid model does provide a solution that can be implemented with a bit of post-solution processing.

Figure 6 is a graphical display of the optimal solution to the fluid model. It depicts whether a sku is stored in Warehouse 16 or a reserve warehouse. Each dot on the graph represents a particular sku. Dots above the line are of a higher viscosity. These sku's will be stored in Warehouse 16. Dots below the line have a higher volume, but are less viscous. They will be stored in the reserve warehouses.

Figure 7 illustrates the costs associated with the results. The total cost curve (indicated by $ in Figure 7) represents the total cost to pick from Warehouse 16 and the reserve warehouses. The various actions that make up the total cost curve are the costs associated with picking from Warehouse 16, restocking Warehouse 16 from the reserve warehouses and picking directly from the reserve warehouses. The minimum point on this curve is the least costly combination of picking and restocking with Warehouse 16 designated a forward-pick area. This minimum is the reference point for the optimal slotting solution. For example, a vertical line that intersects this point and the X-axis shows that there are 335,000 sku's in the solution. A horizontal line intersecting this minimum point and the Y-axis shows that the total cost associated with the optimal solution is $3,152,775. There are three other curves in Figure 7. They represent the number of picks made from Warehouse 16 (forward picks), the number of picks made from the reserve warehouses (reserve picks) and the number of restocks to replenish Warehouse 16 (restocks) when Warehouse 16 is converted to a fast-pick area.

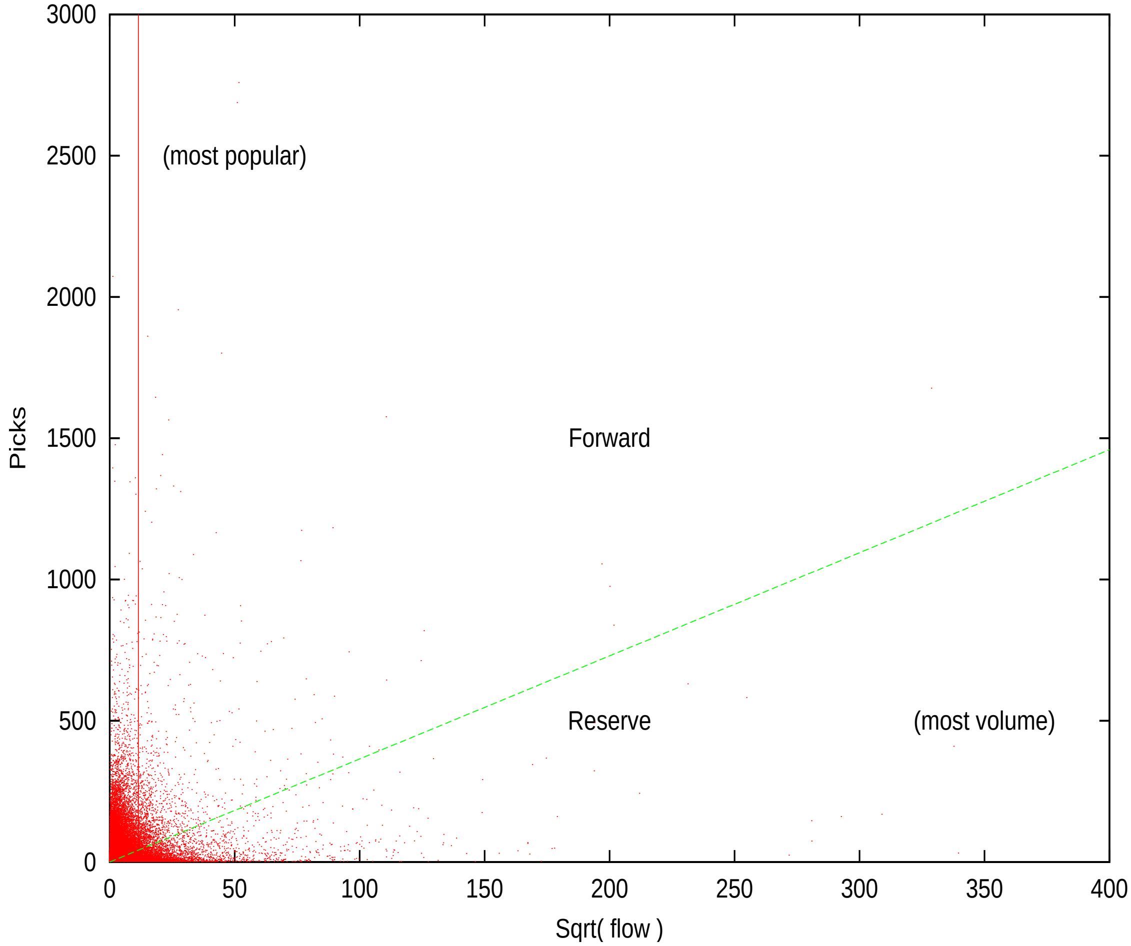

Figure 6. A graphical representation of the optimal solutions sku placement. Each dot represents an individual sku. Dots above the line are stored in Warehouse 16. Dots below the line are stored in reserve warehouses. (From: [Ref. 13])

The forward pick curve starts with the single most viscous sku being stored in Warehouse 16. Notice that this results in all other picks coming from the reserve warehouses. The model then adds the second most viscous sku for storage in Warehouse 16, which decreases the number of picks required from the reserve areas. This process is continued until adding an additional sku to Warehouse 16 results in an increase in the total cost. A vertical line drawn through the minimum point on the total cost curve intersects the forward pick curve at this point. This represents the number of picks made from Warehouse 16 when optimally slotted. The forward pick

curve is concave or increasing at a decreasing rate because the marginal return from adding each successive sku is less than the return received from adding the previous sku.

The reserve picks curve starts with all picks coming directly from the reserve warehouses. Notice that this results in zero picks coming from Warehouse 16. As the model adds sku's to Warehouse 16 this results in a decrease in the number of picks made from the reserve warehouses. This process is continued until removing an additional sku from the reserve warehouses results in an increase in the total cost. A vertical line drawn through the minimum point on the total cost curve intersects the reserve pick curve at this point. This represents the number of picks from the reserve warehouses when Warehouse 16 is optimally slotted. The reserve pick curve is convex or decreasing at a decreasing rate because the marginal return from removing each successive sku is less than the return received from removing the previous sku.

The restocks curve starts with zero replenishments to Warehouse 16. This is because at this point all of the sku's are stored in the reserve warehouses. Again, the model adds sku's to Warehouse 16. As each additional sku is added this results in less available storage volume per sku which makes restocking necessary. The number of restocks required when Warehouse 16 is optimally slotted is where a vertical line drawn through the minimum point on the total cost curve intersects the restock curve. This curve is increasing at an increasing rate because, as the total volume per sku decreases additional restocks are required.

Out of a possible 417,000 sku's eligible for storage in Warehouse 16 there will be 335,000 actually stored there when it is optimally slotted. This will result in 91% of DDJC's picks coming directly from Warehouse 16.

Table VI provides the total costs associated with the optimal slotting solution, compared to current costs. The number of restocks required is an area of concern because it will require a major change to DDJC's current operations in Warehouse 16. The number of restocks—68,098 is 7.5 times more restocks than that currently

experienced at Warehouse 16.

			Proposed		Current
	Cost per	**Quantity**	**Cost**	**Quantity**	**Cost**
Restocks	$3.28	68,098	$223,361.44	9,000	$29,520.00
Forward Pick	$.50	4,300,000	$2,150,000.00	1,657,826	$828,913.00
Reserve Pick	$1.69	461,191	$779,412.79	2,801,903	$4,735,216
Total Cost			$3,152,774.23		$5,593,649.00

Table VI. The total operating costs of when Warehouse 16 is optimally slotted compared to current operating costs.

DDJC currently has only one employee on the second shift dedicated to the task of restocking Warehouse 16. The current problems associated with DSS make the number of restocks required by the optimal solution a matter of concern. Warehouse 16's current warehousing division will require an additional 7 employees to accommodate this increase in restocks. We believe DDJC should be able to reposition workers from outlying warehouses to Warehouse 16 to accomplish the increased number of restocks, because reserve picks in outlying warehouses decrease from 2,801,903 to 461,191 when Warehouse 16 is optimally slotted.

The average time supply from the optimal solution is very high (50 years) because no upper limit was set for on hand inventory. This problem can be addressed by placing an upper limit on the model, as stated in Section II E. DDJC management suggested a two year cap be used as a upper limit. The effects of upper limits are that fewer of each sku will be carried, and more sku's will be stocked in Warehouse 16. Normally, a higher number of restocks would occur, but since the entire quantity of sku's could potentially fit in the forward pick area, the result will almost certainly be fewer restocks. It is even possible that all sku's could be located in Warehouse 16 and all of the available storage V not be utilized. In this case a true fast-pick area could be operated within Warehouse 16 with portions of Warehouse 16 designated as reserve storage.

We were unable to obtain results with upper bounds in sufficient time, an so include them in our recommendation for future work.

B. THE IMPORTANCE OF BIN SIZE

To realize the full benefit of the fast-pick model all available storage space has to be fully utilized. When the fast-pick model is run, the output provides the total bin volume of storage needed per sku. If the quantity of individual bin sizes currently available is different than what the fast-pick model determines, a mismatch occurs. If the recommended sku quantity's cube is less than that of the bin, it will result in wasted storage space. Conversely, if DDJC has too many small bin sizes, the recommended sku quantity will not fit and multiple locations will be required to reach the optimal slotting solution. For example, Figure 8 shows the ideal distribution of bin sizes. It compares DDJC's bin volumes with the optimal slotting solution. Ideally, these two should match. As Figure 8 shows, the available bin volumes do not exactly match what would need to be allocated for the optimal solution. Though they do not match exactly they are fairly close and require minimal adjustments. Each TSC represents available cubic feet of storage space. DDJC has agreed to increase or decrease the number of current TSC's available to better match the optimal solution.

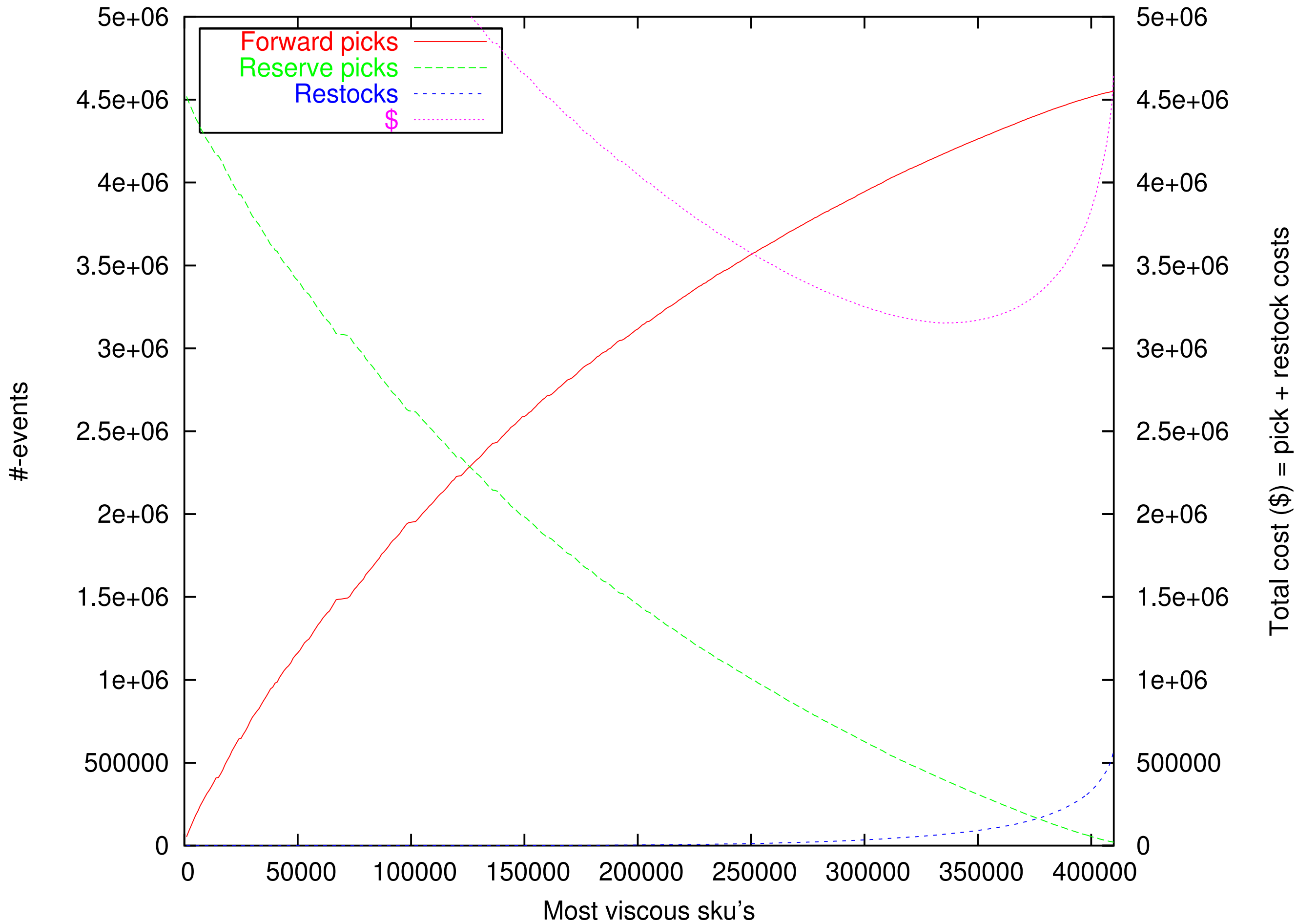

Figure 7. A graphical representation of the costs associated with the optimal solution. The forward picks curve shows the costs associated with picks made from Warehouse 16. The reserve picks curve depicts the cost associated with picking from the reserve warehouses. The cost to restock Warehouse 16 from the reserve warehouses, is shown on the restocks curve. The $ curve is the total cost curve for these three functions. (From: [Ref. 13])

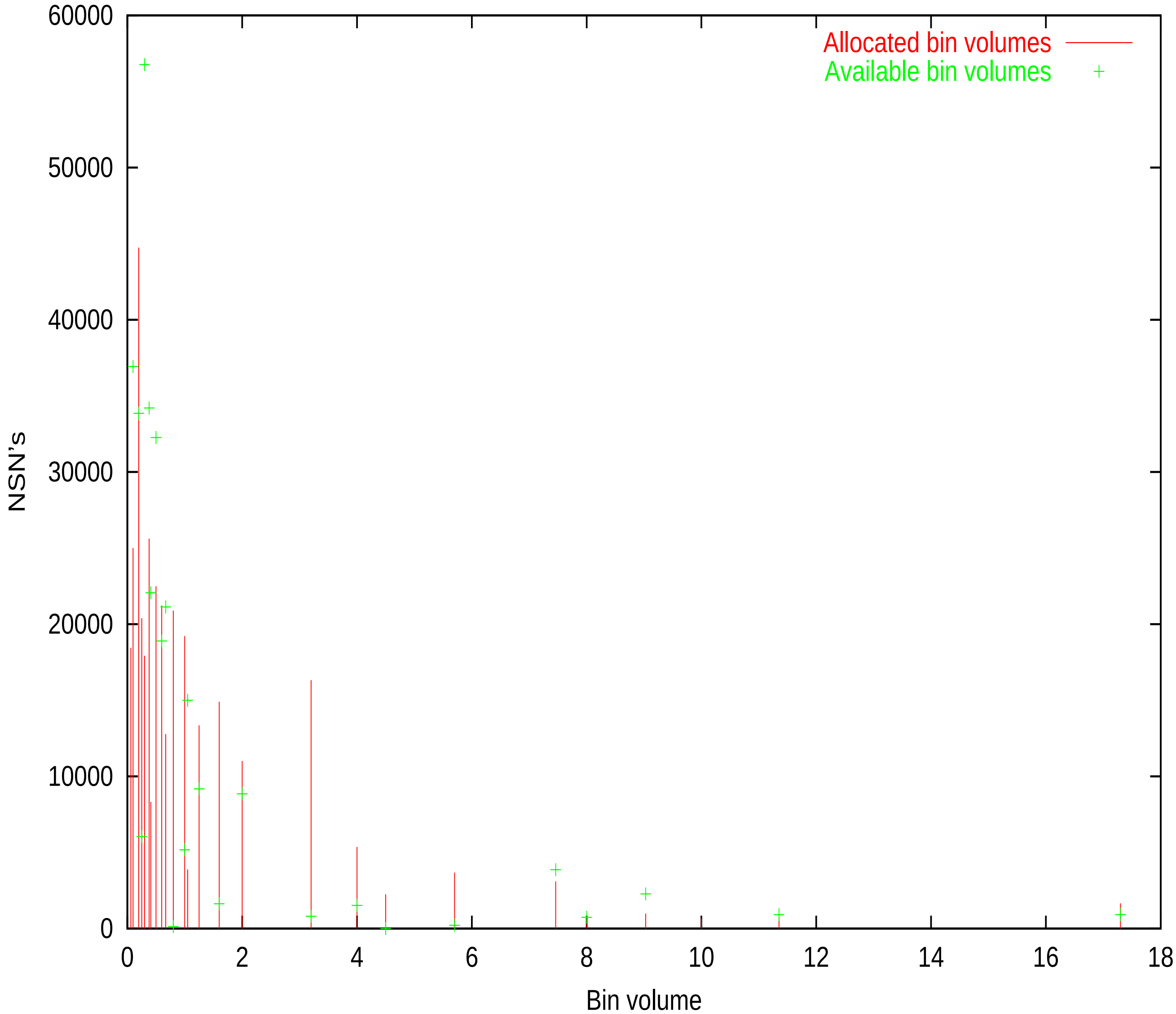

Figure 8. Ideal distribution of bin sizes compared to DDJC's current bin sizes. Plusses represent bin storage available in Warehouse 16. Lines indicate bin storage required for implementation of the fast-pick model. (From: [Ref. 13])

THIS PAGE INTENTIONALLY LEFT BLANK

V. IMPLEMENTING THE FAST-PICK MODEL

A. SKU MOVEMENT

We described the theory behind Bartholdi and Hackman's fast-pick model and the options available to management at DDJC. Transforming Warehouse 16 to a fast-pick area will involve the handling of significant amounts of material. There are five categories of sku's that require movement into or out of Warehouse 16.

1. Sku's held exclusively in reserve warehouses that require movement to Warehouse 16.
2. Sku's held in Warehouse 16 that should only be stored in reserve warehouses.
3. Sku's held in Warehouse 16 in insufficient quantities that require material to be transferred from the reserve warehouses to Warehouse 16.
4. Sku's held in Warehouse 16 in excessive quantities that require material to be transferred from Warehouse 16 to the reserve warehouses.
5. Sku's held in Warehouse 16 in quantities that require no action.

Of the five categories mentioned above, it is beneficial to rank three of them in terms of popularity. This will facilitate receiving the greatest benefit in the shortest amount of time when transitioning to a fast-pick area. Categories one, three, and four apply.

Category one items are not stored in Warehouse 16 and require movement from the reserve warehouses into the fast-pick area. These items need to be ranked by popularity (highest annual demand) in descending order. This will enable DDJC to receive the net benefit of picking from Warehouse 16 instead of the reserve warehouses in the shortest amount of time.

Category three items require movement from the reserve warehouses to increase the quantities currently stored in Warehouse 16. These items also need to be

Type of Activity	Number per Hour
Rewarehousing	6
Stows	11
Picks	25

Table VII. Warehouse 16 employee performance standards used by DDJC management.

ranked by popularity (highest annual demand) in descending order. This will result in the same net benefits described above for category one items.

Category four items require movement from Warehouse 16 to decrease the quantities currently stored there. These items need to be ranked by volume consumed in descending order. This results in the removal of the sku's that consume the most volume of storage space first. This frees up the limited storage space avaiable in Warehouse 16 sooner to allow for the transfer of category one and three items.

Category two items require their complete removal from Warehouse 16 to the reserve warehouses. Simply removing the total quantity of a particular sku stored in Warehouse 16 and then transferring it to a reserve warehouse requires significantly less effort than re-warehousing, stowing, or picking a specific quantity of a given sku. Table VII shows DDJC's performance standards for employees to determine costs associated with warehousing operations. [Ref. 10]

The removal of category two items in their entirety will allow warehouse employees to go to a particular storage location and remove all of the items there. This requires less effort than re-warehousing, stowing, and picking and can be accomplished at a rate higher than 25 per hour. This makes it desirable to remove all of these items from Warehouse 16 in one massive effort.

Category five items remain in their current quantities in Warehouse 16 and the reserve warehouses and require no further action.

B. MOVEMENT OF ITEMS DURING REWAREHOUSING

Transitioning from the current warehouse operations at DDJC to the proposed fast-pick model requires the movement of thousands of sku's into and out of Warehouse 16. This will require significant amounts of labor that can be accomplished by using internal or external resources. Both of these options have associated costs and benefits.

Utilizing organic assets to transfer the required sku's requires the least amount of preparation but takes the longest amount of time. This is due to the fact that this option simply requires the refocusing of current employees' efforts to the task of re-warehousing Warehouse 16. The challenge here is that it requires balancing the re-warehousing effort with normal operations. This allows for less dedicated time towards re-warehousing and extends the time necessary to implement the fast-pick model. This makes it desirable to further subdivide categories one, three and four items into manageable blocks to ensure they receive the net benefits as quickly as possible while they slowly transition to the desired end state (i.e. one hundred most popular sku's in ascending/descending order).

This "in-house" option also makes it desirable to rank category two items based on cube since using current employees precludes the removal of these items in one massive effort. If the "in-house" option is used these items will need to be ranked in descending order based on the amount of volume each sku occupies in Warehouse 16. This contradicts our earlier statement that category two items need not be ranked, which was based on the conclusion that category two items should be removed as expeditiously as possible.

C. BENEFITS AND DRAWBACKS

The benefits of implementing the fast-pick model using "in-house" employees include a working knowledge of DDJC's warehouse operations (including DSS), the

ability to adjust the implementation schedule based on daily workload, the option to start whenever convenient, and the elimination of the lengthy and costly competitive bid process. The drawbacks of implementing the fast-pick model using "in-house" employees include the possibility of incurring overtime costs and a longer completion time.

When we consider using external resources to implement the fast-pick model at DDJC there are two options. These include the use of private contractors or military reservists. These two options also have associated benefits and drawbacks. The benefits of using a private contractor are having a dedicated time for implementation, minimal impact on daily operations and the ability to achieve the desired measurable end result based on a detailed statement of work. Drawbacks of this option include the time required to receive competitive bids, the effort required to produce a detailed statement of work and the costs associated with using a private contractor.

Using Military reservists allows DDJC to receive the benefits associated with using both "in-house" and external assets without the drawbacks. Reserve Quartermaster units that support DDJC are trained in warehouse operations and have previous experience working at DDJC during their active duty training periods. [Ref. 14] The following units are currently scheduled to perform their annual two-week training period at DDJC: [Ref. 15]

Unit	Number of Personnel	Date
693 Quartermasters	180	April 2003
355 Quartermasters	75	June 2003
827 Quartermasters	104	July 2003

These scheduled training times allow for a quick implementation associated with using a private contractor. There are also no additional funding costs associated with using reserve personnel.

DDJC has already taken advantage of using reservists to perform re-warehousing functions within Warehouse 16. The 887th Quartermaster Company from Sinton and Alice, Texas re-warehoused more than 2000 line items during August of 2001 in an

effort to increase physical distribution efficiency by relocating stock to Warehouse 16 so that 90% of the MRO's could be selected from there. Though these efforts follow along the same path as the fast-pick model they do not benefit from the mathematical theories developed by Bartholdi and Hackman as discussed in Chapter Two that allow for optimal utilization of limited space available in Warehouse 16. [Ref. 14] These past efforts do, however, show that the reserve personnel can be successfully used to perform the labor requirements associated with transitioning Warehouse 16 into a fast-pick area.

THIS PAGE INTENTIONALLY LEFT BLANK

VI. CONCLUSIONS

A. SUMMARY

We discussed how the A-76 study is causing defense distribution depots to become more concerned with the productivity and operational effectiveness of their organizations. We also described the picking function within a warehouse and its impact on overall operating costs. We looked at the fast-pick model developed by Bartholdi and Hackman and described the science behind it. We presented the current method of operations at DDJC. Finally, we presented the optimal slotting solution based on Bartholdi and Hackman's fluid model. We now make some conclusions and recommendations.

B. CONCLUSIONS

We have three major conclusions: First, we conclude that DDJC will benefit from converting Warehouse 16 to a fast-pick area. The optimal solution presented results in 91% of the picks being made from Warehouse 16. Our research demonstrates that converting Warehouse 16 to a fast-pick area will result in a cost savings of $2.5 million per year. DDJC's solution to the increased number of restocks will reduce this figure if additional personnel are hired.

Second, optimally slotting the fast-pick area results in a significant increase in the number of restocks performed at Warehouse 16. Our research demonstrates that the number of restocks required for a optimal slotting solution increases from 9,000 to 68,098 annually. This shows that DDJC currently has an excessive quantity of each sku stored in Warehouse 16. This results in picking more often from the reserve warehouses at a higher cost.We have discussed that DDJC currently uses only one employee to perform the restock function and that a significant amount of manual interaction is required to perform the restock function within DSS.

Third, the optimal slotting solution cannot be achieved with the current bin

sizes in Warehouse 16. We have shown that the optimal slotting solution for Warehouse 16 requires a perfect match between available and actual storage bin sizes. We discussed DDJC management's reluctance to create new bin sizes and their willingness to increase or decrease the number of TSC's to come as close as possible to the optimal solution. Since the available bin volumes and the required bin volumes are so close together this is not a major area of concern.

C. RECOMMENDATIONS

We recommend converting Warehouse 16 to a fast-pick area to reduce the costs associated with picking and restocking at DDJC. This allows DDJC to benefit from the science associated with the fast-pick model by focusing their efforts to concentrate the location of fast-moving items in a single area, close to their modes of conveyance.

There are two problems associated with the optimal solution— they are a mismatch of bin sizes within Warehouse 16 and the number of restocks required. We recommend DDJC modify the quantities of their TSC sizes to best match the requirements of the fast-pick model. The number of employees assigned to restock Warehouse 16 will have to be increased. DDJC should continue with DLA's initiative of validating the weight and cube of sku's to reduce the human interaction required with DSS for the restocking function. We recommend running the model again with two-year upper limits imposed on the on-hand inventory levels. (At the time of writing this thesis, such a study was underway.)

We believe the best method to transform Warehouse 16 to a fast-pick area would be to use reserve personnel currently scheduled for active duty training at DDJC.

LIST OF REFERENCES

[1] Defense Logistics Agency, Functions of a Distribution Center, *http://www.ddc.dla.mil/sites/functions.asp*, November 15 2002.

[2] Pike, John, Tracy Facility, San Joaquin Depot, *http://www.globalsecurity.org/military/facility/tracy.htm*, November 2001

[3] Interview between D. Ennis, Defense Distribution Center San Joaquin, and the authors, October 11, 2002.

[4] Interview between Colonel E. Visker, Defense Distribution Center San Joaquin, and the authors, November 8, 2002.

[5] Frazelle, Edward H., *World-Class Warehousing*, Logistics Resouces International, Inc., 1996.

[6] Bartholdi, John J. and Hackman, Steven T., *Warehouse and Distribution Science* Release 0.08, August 23, 2000.

[7] Defense Distribution Center San Joaquin, Telesis 21 Our Journey to Excellence, DDJC's Business Plan, 2002.

[8] Interview between J. Olega, Defense Disrtibution Center San Joaquin, and the authors, October 11, 2002.

[9] Interview between R. Cook, Defense Distribution Center San Joaquin, and the authors, October 11, 2002.

[10] Interview between J. Olega, Defense Distribution Center San Joaquin, and the authors, November 8, 2002.

[11] Interview between R. Lacy, Defense Distribution Center San Joaquin, and the authors, December 2, 2002.

[12] Interview between K. Brown, Defense Distribution Center San Joaquin, and the authors, December 2, 2002.

[13] Bartholdi, John J. (13 March 2003). *Data Files* [e-mail to E. Burks], [online]. Available e-mail: ehburks@nps.navy.mil

[14] Doug Imberi, 877th Quartermasters Lend a hand in DDJC Stock Positioning Project *http://www.ddc.dla.mil/review/Spring2002/877th%20Quartermasters.pdf*, March 22 2002.

[15] Interview between M. Flores, Defense Distribution Center San Joaquin, and the authors, February 11, 2003.

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, VA

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, CA

3. Commander
   Defense Distribution Depot San Joquin
   Stockton, CA

4. Professor Kevin R. Gue, PhD.
   Naval Postgraduate School
   Monterey, CA

5. Commander Kevin Maher
   Naval Postgraduate School
   Monterey, CA

6. John J. Bartholdi III, PhD.
   Georgia Institute of Technology
   Atlanta, GA